

## INVESTIGATION OF THE STRESSED-STRAINED STATE OF CERMET DENTURES USING DIGITAL LASER SPECKLE-PHOTOGRAPHIC ANALYSIS

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*It has been shown that the method of digital dynamic speckle photography is an efficient method of quantitative and qualitative diagnostics in orthopedic stomatology for optimization of the constructions of cermet dentures by evaluating their stressed-strained state. Determination of the stressed-strained state of cermet dentures by the method of digital laser speckle photography at the stages of their manufacture makes it possible to most reliably investigate the quality of manufactured constructions, which diminishes the number of complications and improves the efficiency of treatment in orthopedic stomatology.*

**Keywords:** *stressed-strained state, diagnostics, speckle photography, cermet denture.*

**Introduction.** In orthopedic treatment of dentition defects, one widely uses cermet dental prostheses (dentures) of high esthetics and strength. However, strong stresses can arise at the juncture of the metal frame of the denture and the ceramic coating; these stresses give rise to fracturing, spalling, and breaking-off in the ceramics under stress situations. This significantly diminishes the functional capabilities of a therapeutic appliance and substantially affects its clinical performance and characteristics. To elucidate the reasons why dentures fail during use we must know the strain and stress distribution in them on application of a load. Functional evaluation of dentures at the stages of their manufacture is one important factor ensuring good results of orthopedic dental treatment. The imperfection of certain methods of investigation in prosthetic dentistry (orthopedic stomatology) often leads to the fact that practical experience based on clinical observations and the doctor's intuition often produces objective scientific data. Investigation of today's procedures for diagnostic evaluation of manufacture of dentures with allowance for their stressed-strained state is a topical current problem of orthopedic stomatology [1, 2].

Until recent times, the most promising method of evaluation of the stressed-strained state of teeth and dentures was the holographic method of investigation. However, the process of recording and processing of holograms is quite difficult and time-consuming. The low sensitivity of photographic materials requires exposures of the order of seconds; "wet" processing of photographic plates or servicing of thermoplastic recorders and visual reading of interferograms requires special skills of the operators. Large data arrays should be stored on photographic plates, or photographs of the holograms should be taken. Not only does today's photographic and computer facilities help in solving certain problems of obtaining, storage, reading, and processing of holographic interferograms but they also furnish another opportunity. Just as the appearance of lasers changed the situation in experimental optics, so high-performance computers produced one more substantial change: the photographic detector was replaced by a digital video system with computer recording of digitized data on different, virtually unlimited in number, exposures of the process of measurement of displacements and further processing of these data. This method was called digital dynamic speckle photography. Its important feature is that we can record a virtually unlimited number of exposures and subsequently use their arbitrary combinations. Each combination will reflect the shift of an object between exposures. We can compare not only static-state pictures but also pictures taken during the motion of the object: we must only select the exposure time and the time between exposures. Thus, processing a series of digital speckle photographs, we can reproduce the motion of an object with submicron accuracy. The method of digital dynamic speckle photography ensures high-sensitivity measurements of the fields of individual components of the displacement vector [3, 4], which is

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a substantial advantage compared to the holographic-interferometry method. Determination of the tangential components from holographic interferometers is a rather difficult problem. At the same time, we can construct a holographic interferometer possessing sensitivity only to the normal component of the displacement vector. The basic advantages of speckle photography lie in lower requirements imposed on mechanical stability and coherence, easily retunable sensitivity, and simplicity of displacement measurements in the plane. The process itself of recording interference patterns is much more rapid, which makes it possible to process results in real time [3, 4].

The present investigation seeks to use the new method of laser diagnostics in orthopedic stomatology for optimization of the construction of cermet dentures by evaluating their stressed-strained state.

**Materials and Methods.** To attain this aim we have developed an experimental scheme and procedure for evaluation of the stressed-strained state of dentures on the basis of laser probing and digital recording of speckle fields that occur in the scattered investigated object of laser radiation.

The scheme of digital speckle photography is based on the wide use of computers in processing digitized speckle fields. With this method, requirements imposed on the resolving power of a recording system are much lower than those, e.g., in holographic interferometry, which explains the wide use of high-resolution photographic facilities for recording of light fields in correlation speckle photography. The method mentioned above is based on the experiments of Burch and Tokarskii [5] in which it was shown that interference fringes that are analogous to the fringes occurring in a Young interferometer with two slits which are  $\Delta$  apart are the Fourier transform of a doubly exposed speckle field shifted by a certain  $\Delta$  between exposures. In succeeding years, the results of these investigations were generalized in a series of monographs and fundamental reviews [3, 6, 7]. The intensity distribution in the far zone in the diffraction of a plane coherent wave on the hole of diameter  $b$  is known to be described by the following equation:

$$I_h = I_0 \left[ 2 \frac{\mathfrak{S}_1 \left( \frac{\pi br}{\lambda L} \right)}{\frac{\pi br}{\lambda L}} \right]^2. \quad (1)$$

The intensity distribution in diffraction on the slit of dimension  $b$  will have an analogous form:

$$I_h = I_0 \frac{\sin^2 \left( \frac{\pi br}{\lambda L} \right)}{\left( \frac{\pi br}{\lambda L} \right)^2}. \quad (2)$$

In this case the diffraction pattern has no circular symmetry and the coordinate  $y$  in the observation plane is reckoned from the origin of coordinates in the direction orthogonal to the orientation of the slit. The diameter of the central disk in the distribution (Airy disk) will be found from the formula

$$d_A = 2.44\lambda \frac{L}{b}. \quad (3)$$

In the diffraction of light on two slits or holes that are  $\Delta$  apart, the diffraction pattern turns out to be modulated by interference fringes described by the following equation:

$$I = I_h \cos^2 \frac{\pi \Delta y}{\lambda L}. \quad (4)$$

The fundamental importance of the experiments of [5] lies in the fact that the diffraction on a system of numerous randomly arranged holes or pairs of holes occurs analogously to what has been described above. Such a system of holes randomly arranged on the screen can be modeled by a speckle field exposed on a photographic plate. The Fourier transform of this speckle field is a speckle field, too, but its mean intensity (averaged over numerous in-

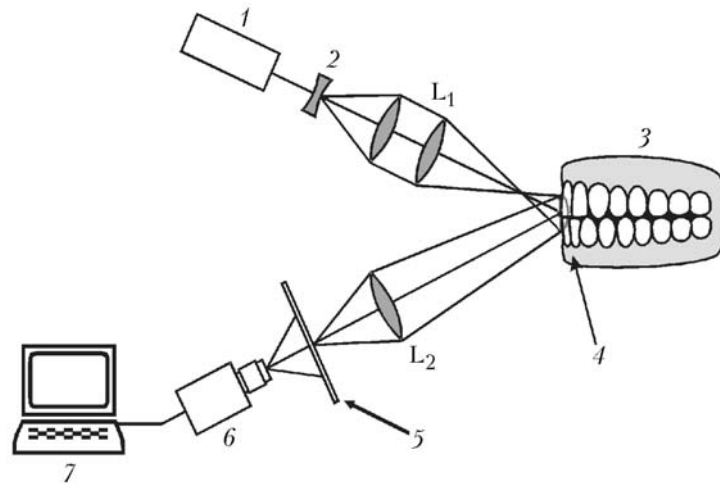


Fig. 1. Block diagram of the experimental bench for investigation of stressed-strained states in dentures: 1) probing laser; 2) collimator; 3) object under study (denture); 4) illuminated zone; 5) recording plane; 6) digital camera; 7) personal computer;  $L_1$  and  $L_2$ , lenses.

dividual speckles) will change in accordance with expressions (1)–(4). Analogously the diffraction on two speckle fields shifted by a certain distance  $\Delta$  relative to each other and exposed on one photographic plate will be equivalent to the diffraction on two slits in the Young interferometer. Therefore, the speckle field on the screen will be modulated by Young interference fringes.

Thus, measuring the distance between the interference fringes  $d_f$ , we can unambiguously determine the value of the shift of speckle fields between exposures:

$$\Delta = L\lambda/d_f. \quad (5)$$

Taking into account that the interference fringes are oriented perpendicularly to the direction of the shift of speckle fields, we compute both the value and direction of the shift of a speckle field between exposures, i.e., two components of the displacement of the speckle field in the plane  $(x_1, y_1)$ :  $\Delta_{x_1}$  and  $\Delta_{x_2}$ . When a speckle field formed by reflection from a rough surface is photographed, the speckles in the image plane are displaced in proportion to the displacements of the corresponding points of the scattering surface; the proportionality factor is the magnification factor in the formation of a speckle field in the image plane  $M$ .

It is noteworthy that digital speckle photography is a simple and convenient method of determination of the strain field of the specimen under study, which makes it possible to reproduce, at each point of the surface, the vector of its displacement during the period between the pulses of illumination of the surface by coherent radiation.

**Experiment.** Investigations of stressed-strained states in full-scale models of cermet dentures have been carried out with an experimental bench for digital dynamic speckle photography (Fig. 1) at the Laboratory of Physicochemical Hydrodynamics of the A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus. Bridge cermet dentures of the front portion of the lower and upper jaws (mandible and maxilla) were the objects of investigation. The denture was installed in a gypsum model and thereafter was placed on the objective table of an experimental setup (Fig. 2a). An optical scheme for recording of speckle photographs with a denture was assembled on this setup. The load was applied to the cutting edge of false teeth and was varied from 20 to 70 N. We investigated 12 bridge dentures with different thicknesses of the metal frame (0.3 to 0.6 mm) and different thicknesses of the ceramic mass (0.8 to 1.2 mm). An LGN-223 He–Ne laser of power 7 mW with a wavelength of 0.63  $\mu\text{m}$  was used. The laser radiation scattered by the model formed, using the optical system, a speckle image that was subsequently recorded with a Nikon D70S high-precision digital camera (Japan) (Fig. 2b). During the test experiments, we recorded two successive images: the initial image and the model's image displaced by a certain assigned distance. The experimental results were numerically processed using the program created at the Heat and Mass Transfer Institute of



Fig. 2. General view of the experimental setup with the specimen under study (a) and the unit for digital recording of experimental images (b).

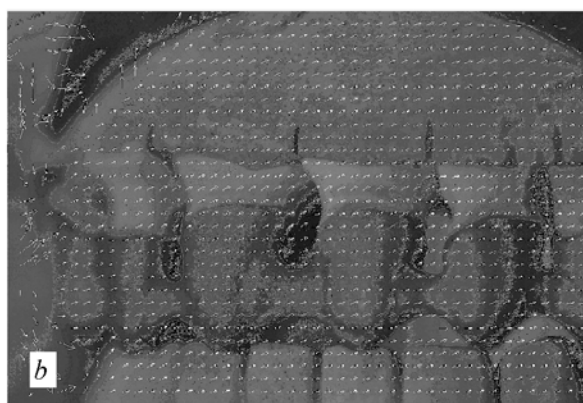
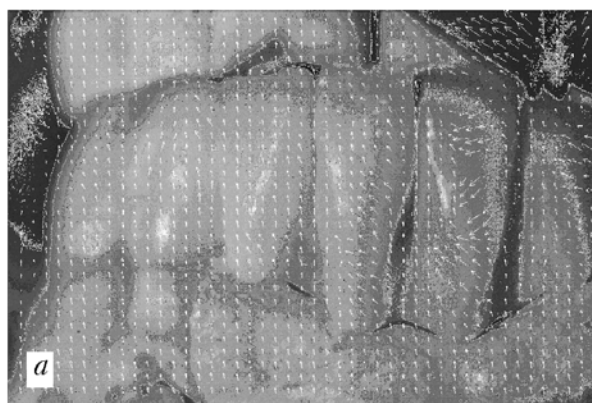


Fig. 3. Digital speckle photographs of two specimens of cermet dentures under load after their statistical processing: 1) specimen with ceramic crowns (load 70 N); b) specimen without crowns (load 50 N).

the National Academy of Sciences of Belarus. From the position and value of the calculated displacement vectors, we reliably determined the true displacement of the model in the experiments. The test experiments carried out made it possible to reproduce the value and direction of the shift (shear) of the denture models with a high accuracy.

Figure 3 gives digital speckle photographs of two different constructions of a cermet denture after statistical processing, as a result of which we determined the stressed-strained state arising in the analyzed specimens under load from the position and value of the displacement vector.

## CONCLUSIONS

1. The possibility of studying the stressed-strained state of orthopedic constructions of cermet dentures at different stages of their manufacture by the method of digital laser speckle photography has been shown.

2. Determination of the stressed-strained state of cermet dentures by the method of digital laser speckle photography makes it possible to most reliably investigate the quality of the manufactured constructions, which contributes to decreasing the number of complications and improves the efficiency of treatment in orthopedic stomatology.

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## NOTATION

$b$ , diameter of the hole or width of the slit in the Young interferometer, m;  $d_A$ , diameter of the Airy disk, m;  $d_f$ , distance between the interference fringes, m;  $I_0$ , initial laser-radiation intensity,  $W/m^2$ ;  $I_h$ , radiation-intensity distribution in the halo region,  $W/m^2$ ;  $L$ , distance from the diaphragm to the screen, m;  $M$ , factor of optical magnification of the system;  $(x_1, y_1)$ , coordinates in the observation plane, m;  $y$ , coordinate reckoned, in the observation plane, from the direction which is orthogonal to the slit orientation, m;  $\Delta$ , displacement of the speckle field between exposures, m;  $\Delta_{x_1}$  and  $\Delta_{y_1}$ , components of the displacement of the speckle field in the observation plane, m;  $\lambda$ , laser-radiation wavelength,  $\mu m$ ;  $J_1$ , Bessel function of first order. Subscripts: f, fringe; h, halo; 0, initial value of the physical quantity.

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